Senior Thesis

Groundwater Mixing in Northwest Ohio

by
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Abstract

Water samples were taken from three aquifers along a flowpath from Bellefontaine topographic high to the Maumee River. Through the use of mixing triangles constructed using major conservative ion pairs, it has been determined that the water in the shallow carbonate aquifer is a mixture of deep carbonate water and glacial aquifer water. It was also found that the shallow carbonate water is diluted by meteoric water. The Bellefontaine high is a recharge zone where the glacial and deep carbonate aquifer waters mix. The two sites closest to the Maumee River exhibit greatly increased concentrations of sulfate, magnesium, and calcium, which may be due to upward leakage of deep brines through the Bowling Green Fault Zone. Ion concentration trends in water from the glacial wells may be due to variations in the thickness of the glacial cover.

Background

Groundwater samples were collected along a flowpath in northwest Ohio in an area that is part of a larger study area designated as the Midwestern Basin and Arches Regional Aquifer System by the United States Geological Survey (USGS). This is one of 22 projects within the Regional Aquifer Systems Analysis (RASA) program designed to assess regional hydrology, geology and water quality of the most important aquifers in the U.S. (Bugliosi, 1990).

Regional Setting

The Midwestern Basin and Arches, consisting of a Silurian-Devonian carbonate-bedrock aquifer with an overlying Pleistocene glacial aquifer, is approximately 35,000 square miles in area and includes western Ohio and eastern Indiana, from Columbus to

Indianapolis, and from Lake Erie in the north to the Ohio River in the south (Figure 1). The area is bounded by the Appalachian Plateau on the east, the Illinois structural basin to the west, and the Michigan structural basin and Lake Erie on the north. Lateral boundaries are designated by the location of the 10,000 mg/L chloride concentration line in the groundwater, disregarding the fact that the carbonate-bedrock aquifer dips into the basins (Bugliosi, 1990). The 10,000 mg/L chloride concentration line is an indication that little freshwater infiltration across this boundary is taking place. Water with 10,000 mg/L or more chloride concentration is considered to be unpotable because of the salty taste, and is harmful to metallic pipes and structures, as well as to agricultural plants if used for irrigation purposes (APHA,1976).

Geology

The Silurian-Devonian carbonate aquifer is confined above and below and is overlain by unconfined Pleistocene glacial sediment. The upper confining unit of the Paleozoic carbonate aquifer are the unconformable Upper Devonian Antrim shale. The basal confining unit of this aquifer is Upper Ordovician undivided Cincinnatian rocks. Middle Devonian carbonates comprise the upper part of the Paleozoic carbonate aquifer, including the dolomites of the Transverse Formation, which unconformably overlie the conformable Delaware and Columbus Limestones and the Detroit River Group. In addition, a thin unit of Lower Devonian Oriskany-Hillsboro Sandstone lies unconformably at the bottom of the middle Devonian carbonate sequence. Except for the thin Oriskany-Hillsboro Sandstone, the lower Devonian rock sequence is not present in north-central Ohio. The Silurian carbonates consist of a thin layer of Bass Island Dolomite, which, when present in northwestern Ohio, conformably overlies the Salina Formation. The Salina

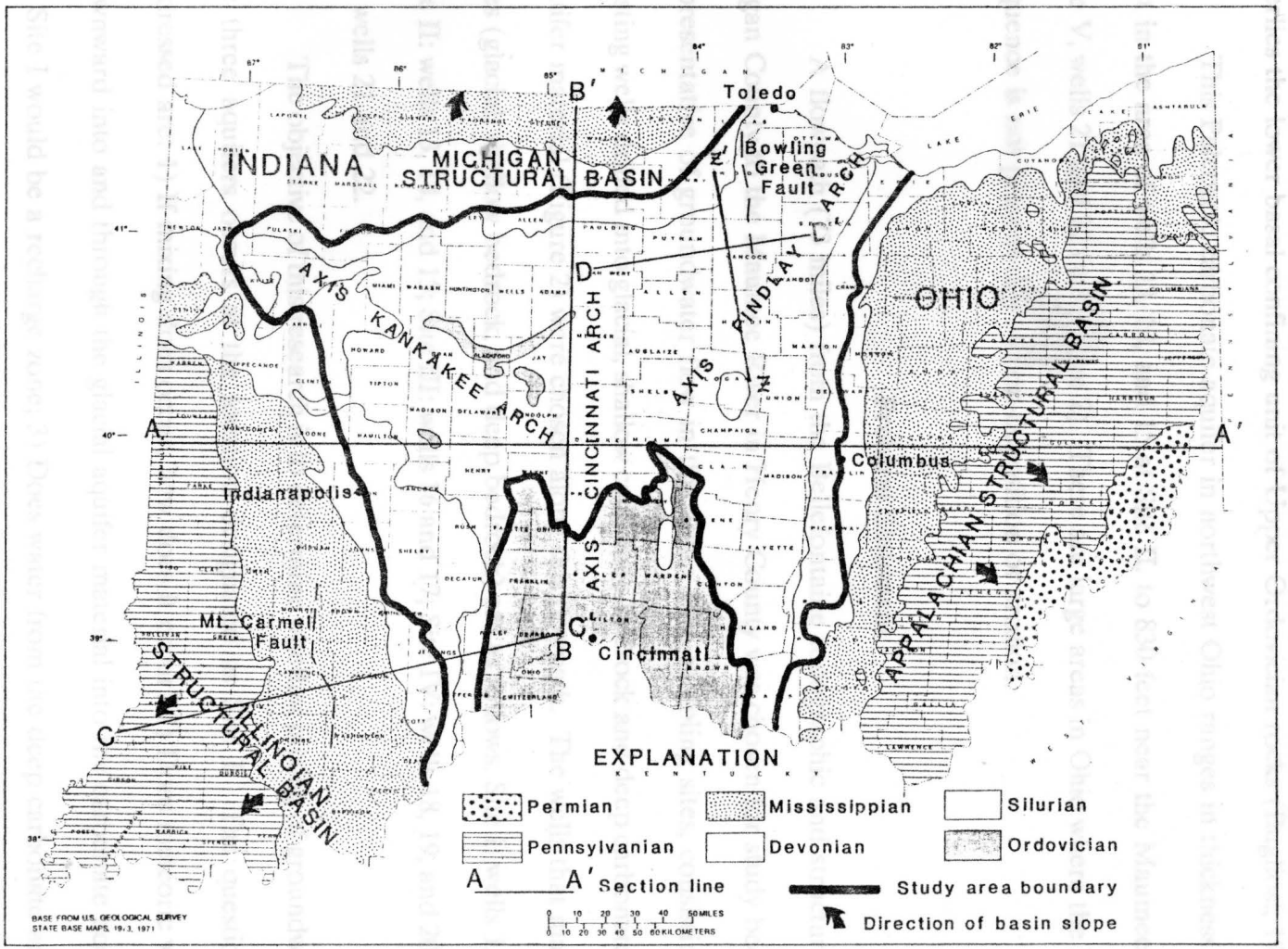

Figure 1. Location Map of Midwestern Basin and Arches RASA showing northwest flowpath (line ZZ") Source: USGS Open File Report 90-151, 1990.

Formation conformably overlies the Lockport Dolomite, a thin laterally extensive shale unit, and the Dayton Limestone. The Dayton Limestone lies unconformably above the Brassfield Limestone of the Cataract Formation. This Silurian sequence unconformably overlies the lower basal confining unit of Upper Ordovician rocks (Bugliosi, 1990).

This Paleozoic carbonate aquifer in northwest Ohio ranges in thickness from 300 feet in the area of wells 13, 14, and 15 at Site II, to 830 feet near the Maumee River, at Site V, wells 21 and 22 (see Figure 2). There are large areas in Ohio where the Devonian sequence is not present due to non-deposition or erosion.

Problem Statement

A flowpath (73 miles) from the Bellefontaine topographic and structural high in Logan County to the Maumee River in Henry County was chosen for study because it is representative of groundwater flow in this area. Five sampling sites, consisting of pre-existing wells drilled into glacial, shallow carbonate-bedrock and deep carbonate-bedrock aquifer material (Figure 2) were chosen along this flowpath. The wells that make up the sites (glacial, shallow bedrock, and deep bedrock) are as follows, Site I: wells 1, 2, and 3; Site II: wells 13, 14, and 15; Site III: wells 16 and 17; Site IV: wells 18, 19, and 20; and Site V: wells 21 and 22.

The objective of this research is to determine whether mixing of groundwater from the three aquifers occurs at the location designated as Site I. The questions to be addressed are: 1) If mixing does occur, how does it occur? 2) Does meteoric water flow downward into and through the glacial aquifer material into the carbonate aquifers? If so, Site I would be a recharge zone; 3) Does water from the deep carbonate aquifer mix with water of the shallow carbonate aquifer and flow upward into and through the glacial

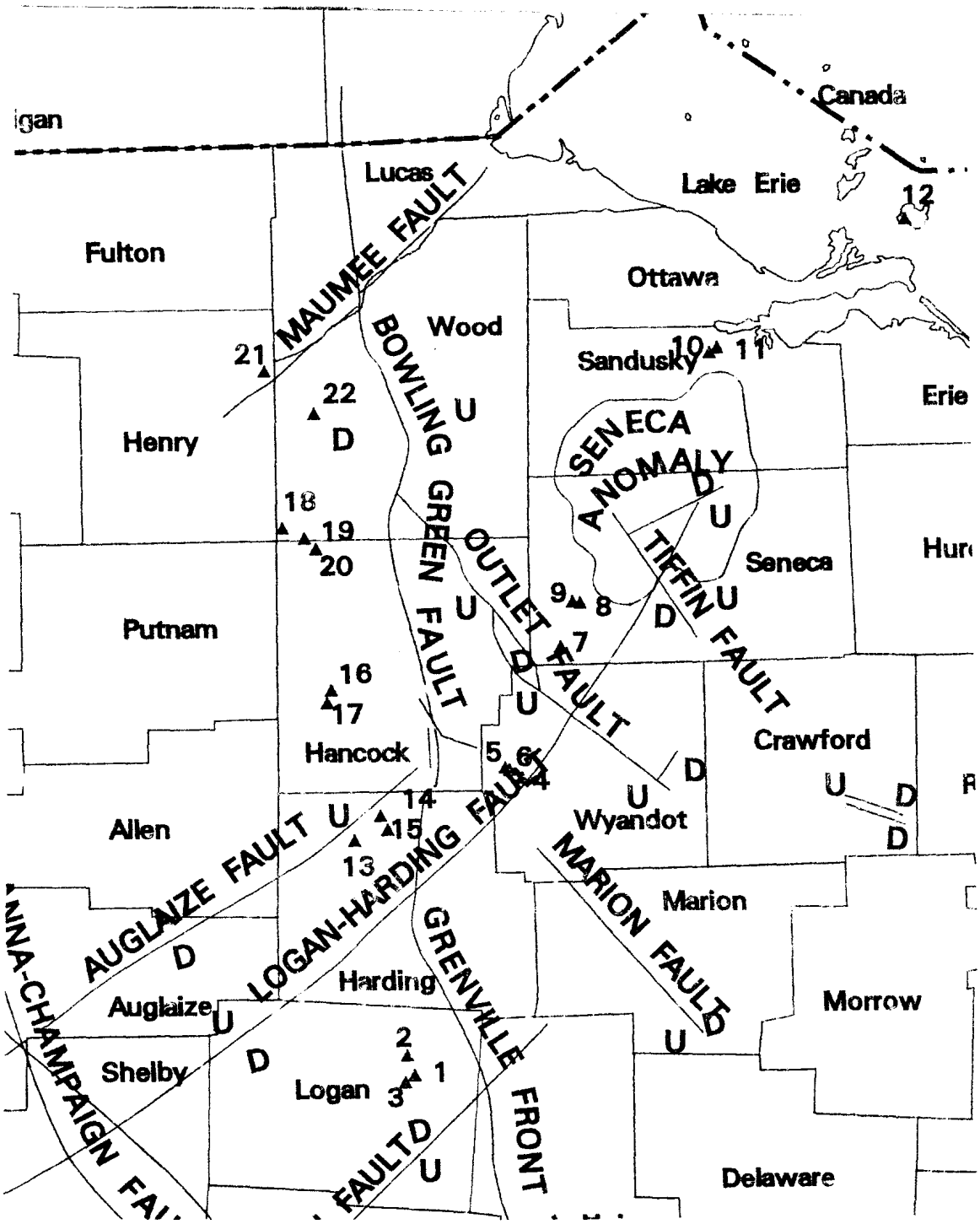

Figure 2. Site and well location map for the Northwest Ohio flowpath from Bellefontaine, Logan County, to the Maumee River, Henry County. Base map: Basement Structures of Ohio, Map DCMS-7, OGS, 1991.

aquifer material? If it does, then Site I would be a discharge zone; 4) Do the different waters mix in the middle aquifer? If they do, then water in the shallow aquifer should have characteristics of water in the other two aquifers; and 5) Do the waters in each aquifer flow independently down-gradient without coming into contact with the others?

Methodology

Sampling sites were chosen within an area one mile wide and 73 miles long, beginning in Logan County near the Bellefontaine topographic and structural high and ending 1.2 miles from the Maumee River in Henry County (line ZZ′, Figures 1 and 2). This area is designated as the northwest flowpath. Five sites were chosen for sampling. Each consisted of three pre-existing wells, one in the surficial glacial aquifer, one at a shallow depth in the carbonate-bedrock, and one in the deep carbonate aquifer. The three wells were chosen to be as close together as possible so that they could be considered as one well sampled at three different vertical intervals. Two sites (III: wells 16 and 17, and V: wells 21 and 22) had only thin glacial cover and, therefore, no glacial aquifer samples were collected. The well depths ranges, measured from the land surface, are: glacial: 50 to 102 feet, shallow carbonate-bedrock: 35 to 81 feet, and deep carbonate-bedrock: 250 to 500 feet. The Silurian-Devonian carbonate formations range in thickness from 300 feet to 830 feet along the flowpath. For the purposes of this study, the carbonate formations have been divided into "shallow" and "deep" aquifers so that water from the top of the carbonate beds can be compared to water from near the bottom of the carbonate beds. The shallow carbonate wells penetrate the top of the carbonate formations between three and 29 feet below the surface. The depth of penetration into the "deep" carbonate is between 210 and 435 feet.

Samples were collected after three well volumes had been pumped from each well casing to ensure that only aquifer water was being sampled. Appropriate sampling methods, containers, and preservation techniques were used (APHA, 1989). The samples were sent to the USGS chemistry laboratories in Arvada, Colorado, where atomic absorption and inductively-coupled plasma emission analyses were performed for dissolved metals. Only the conservative ions of calcium, sodium, magnesium, sulfate, and chloride are used in this study for the interpretation of aquifer mixing and flowpath identification.

The data obtained from the chemical analysis of the water samples from Site I, wells 1, 2, and 3, were interpreted by means of mixing triangles. A ternary diagram is used when three different components make up a mixture of varying proportions (Figure 3). The vertices of the triangle represent the concentrations of conservative elements in the three components. Data points on the interior of the triangle are considered to be as mixtures of the three components at the corners of the triangle (Faure, 1991).

Different combinations of ion pairs were plotted for the three wells at Site I. Figure 3 is a plot of sulfate concentration versus chloride concentrations for wells 1, 2,and 3. Glacial well 1 has high sulfate and low chloride concentrations, while the deep-carbonate well 3 has high chloride and low sulfate concentrations. The shallow-carbonate well 2 has intermediate values of chloride and sulfate, but does not lie on the mixing line joining wells 1 and 3. If a line is drawn from the origin, representing meteoric water, through well 2, to line 1-3, the intersection point Q indicates the amounts of glacial and deep-carbonate waters present in well 2 if it had not been drawn away from the mixing line by dilution with meteoric water.

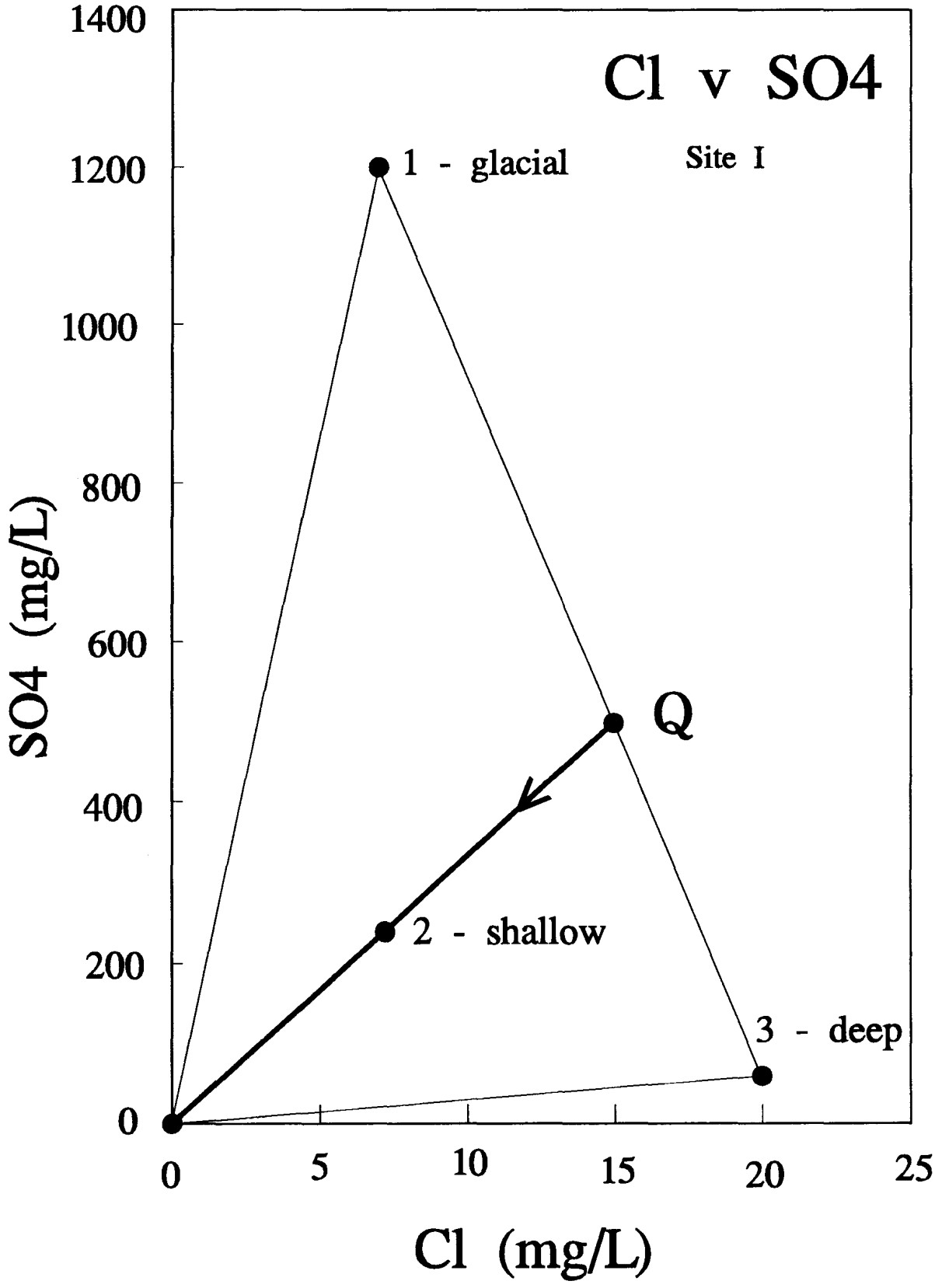

Figure 3. Dilution effect. The effect of dilution by meteoric water on shallow carbonate-rock aquifer water which is a mixture of waters from the glacial aquifer and the deep carbonate-rock aquifer.

A mixing triangle can be created by connecting well 1, high sulfate and low chloride, well 3, high chloride and low sulfate, with the origin containing zero sulfate and zero chloride. Well 2, located within triangle O-1-3, can be considered to be a mixture of meteoric water, glacial water, and deep-carbonate water. If a line is drawn through the origin and well 2 so that the line intersects line 1-3, the point of intersection Q would be the composition of well 2 water if it were only a mixture of water from well 1 and 3. But well 2 water has been drawn away from the mixing line in the direction of meteoric water.

To calculate the fraction of glacial water in well 2 using a mixing triangle (Figure 4), line 1-B is drawn perpendicular to line O-3. Next line 2-B′ is drawn perpendicular to line 1-B through well 2. The lengths of the lines are measured and the ratio B-B′/1-B is then (2.9 cm/15.5 cm) = 0.187. Therefore, the concentration of water from the glacial aquifer in well 2 is equal to 18.7%. The fraction of meteoric water is calculated in the same way, with line O-A drawn perpendicular to line 1-3, and line 2-A′ drawn perpendicular to O-A. The percentage of meteoric water in well 2 (AA′/OA = (4.95 cm/9.60 cm) is 52%. The abundance of water from the deep carbonate aquifer, (100% - (18.7% + 52%)), is 29.3%. Thus, for the ion pair sulfate-chloride, 52% of the water in the shallow carbonate well is meteoric, 18.7% is glacial, and 29.3% is from the deep carbonate aquifer.

Results and Discussion

Figure 5 consists of mixing triangles for calcium, magnesium and sodium versus chloride at Site I. The water from well 2 plots on the interior of the triangles in each case, and the shape of the triangles is very similar.

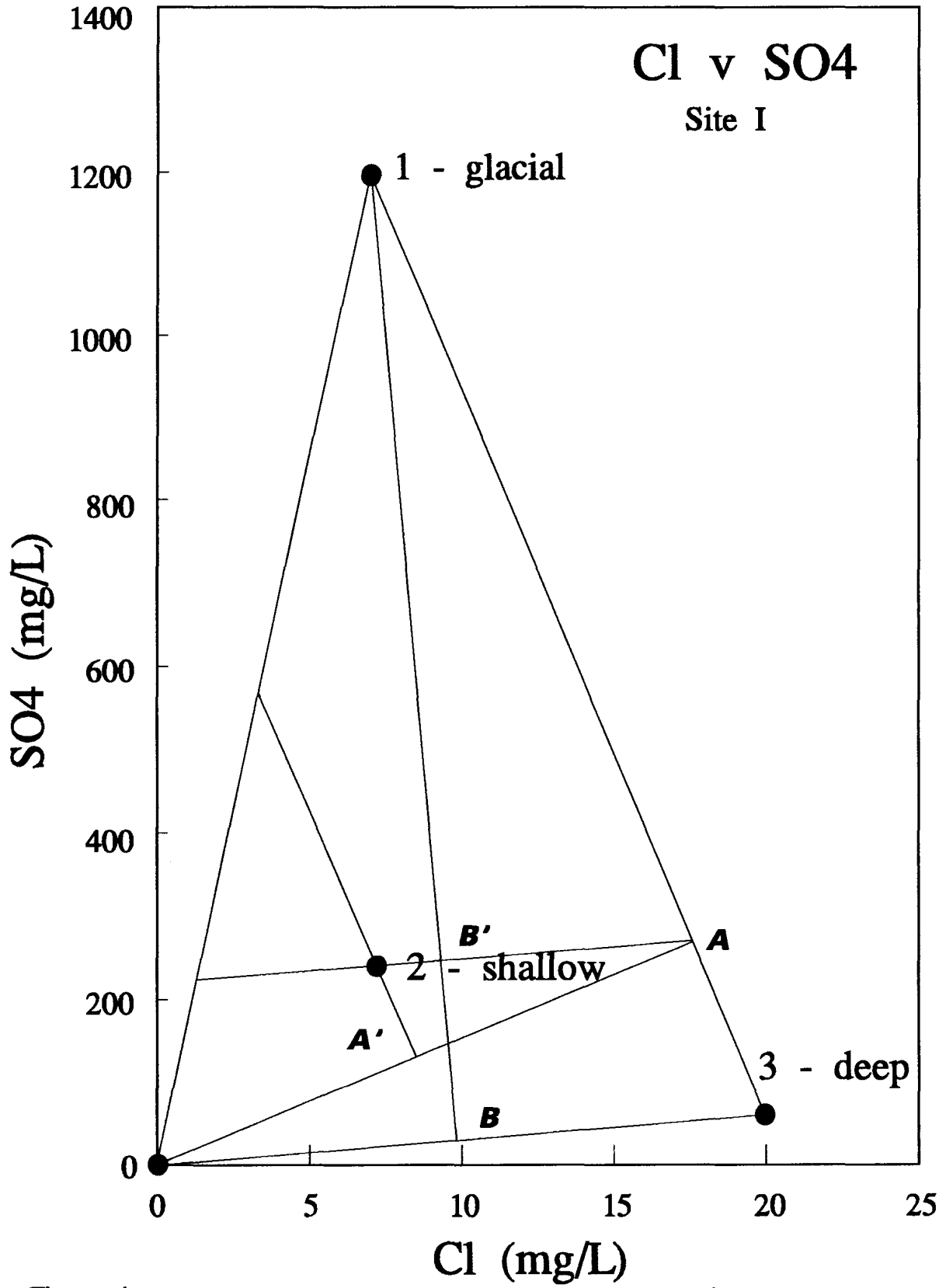

Figure 4. Demonstration of the technique used to determine the percentage of each type of water that constitutes the composite water in well number 2

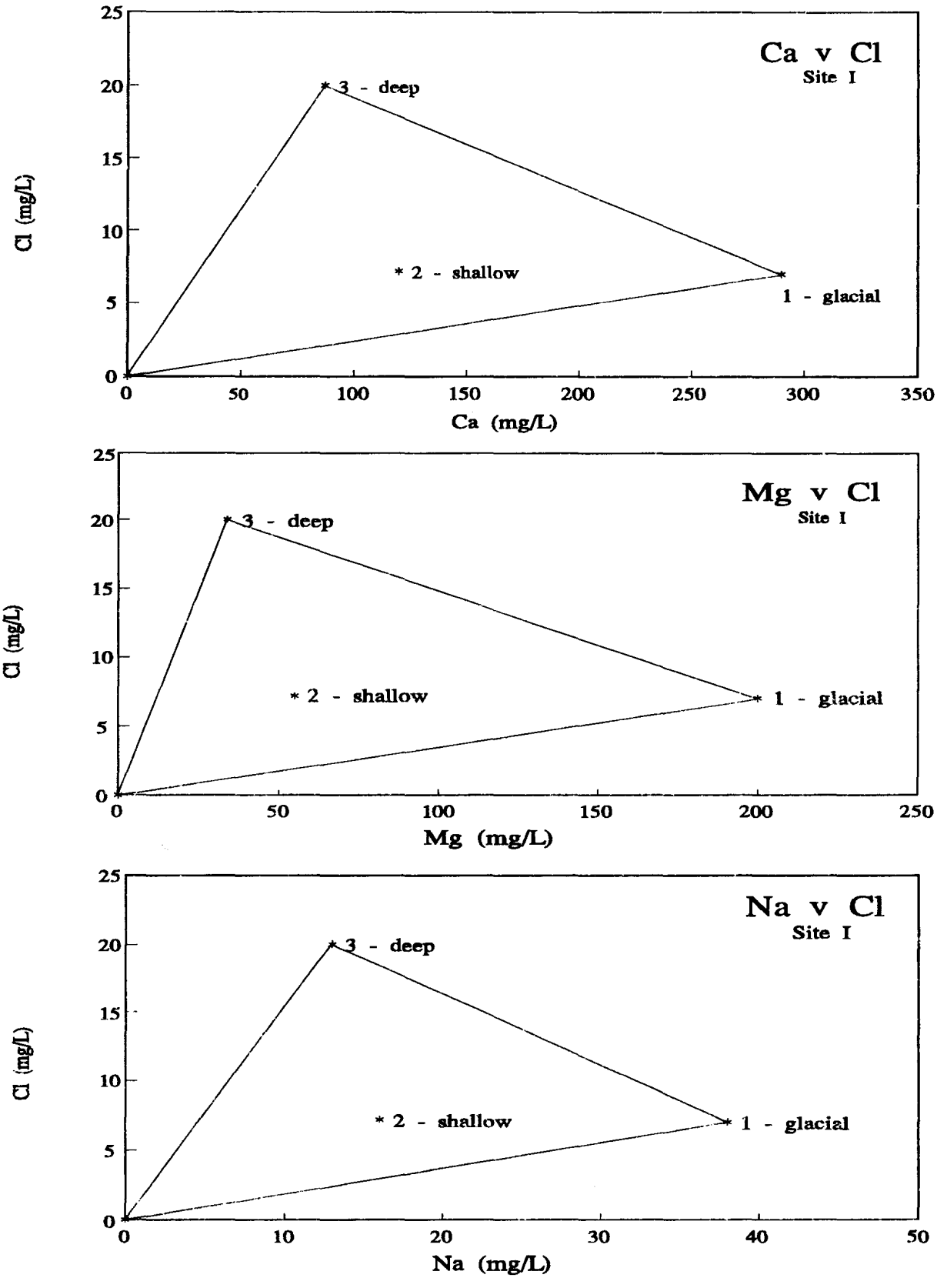

Figure 5. Mixing trangles for calcium, magnesium, and sodium versus chloride at Site I.

Additional ion pairs and the contribution of each type of water to the shallow carbonate aquifer are listed in Table 1. The ion pairs designated with dashes in the table had mixing triangles too small to resolve. The total average contribution of meteoric water to the shallow carbonate water at Site I is 43.2 ± 8.5%, glacial water is 30.0 ± 18.9% and deep carbonate water is 27.0 ± 10.7%. Therefore, Site I at the Bellefontaine topographic and structural high is a recharge zone.

Figure 6 contains plots of cation concentration versus distance, for each of the aquifers and each of the wells from the Bellefontaine high to the Maumee River. Figure 7 is a companion plot of anion concentrations versus distance for the same sampling locations and intervals. The wells in the deep carbonate aquifer show a progressive enrichment in cation and anions as one approaches the terminus of the northern flowpath. Exceptional increases in calcium and sulfate concentrations, rising from 190 mg/L to 540 mg/L, and 530 mg/L to 1900 mg/L, respectively, are notable between well 20, Site IV and well 22, Site V. The magnesium concentration also rises from 73 mg/L to 180 mg/L at the same sites. However, sodium shows only a slight enrichment at well 20, Site V, maintaining the same trend along the entire flowpath, while chloride is essentially flat throughout.

The elevated calcium, magnesium, and sulfate concentrations may be related to the presence of the Bowling Green Fault Zone (BGFZ) (Figures 1 and 2) in the vicinity of Sites IV and V.

Shallow aquifer ion concentrations are fairly uniform throughout the entire distance, with the exception of well 19, Site IV, where concentrations of sodium and sulfate become elevated before returning to previous levels. The shapes of the anion and cation curves for the glacial aquifer mirror each other well. The glacial aquifer, which is not

Table 1. Components of Shallow Carbonate Aquifer Water for Site I

	Meteoric Water %	Glacial Water %	Deep Carbonate Water, %
Cl-Na	31.3	50.0	18.2
Cl-SO_4	51.2	18.7	29.3
Cl-Ca	41.7	35.1	24.1
Cl-Mg	50.8	23.1	27.9
SO_4-Ca	41.4	22.9	35.6
Ca-Na	---	---	---
SO_4-Na	---	---	---
SO_4-Mg	---	---	---
Mg-Na	---	---	---
Ca-Mg	---	---	---
Σ	216.4	149.8	135.1
	x_m = 43.3%	x_g = 30.0%	x_d = 27.0%
%Error	8.5	18.9	10.7
%Error = σ_n/X x 100			

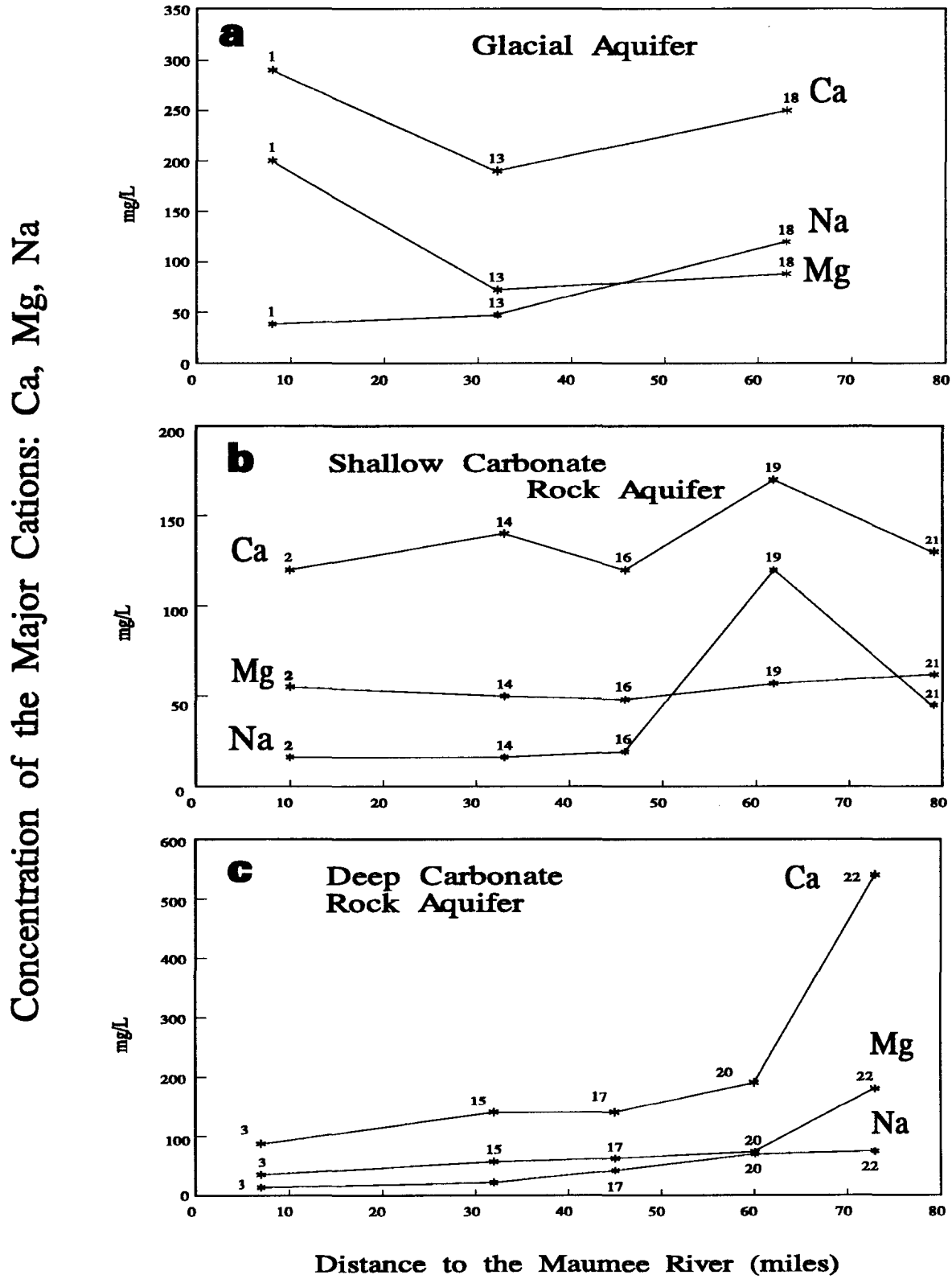

Figure 6. Variation in the concentration of major cations versus distance along the flowpath, a: Glacial Aquifer, b: Shallow Carbonate-rock Aquifer, c: Deep Carbonate-rock Aquifer.

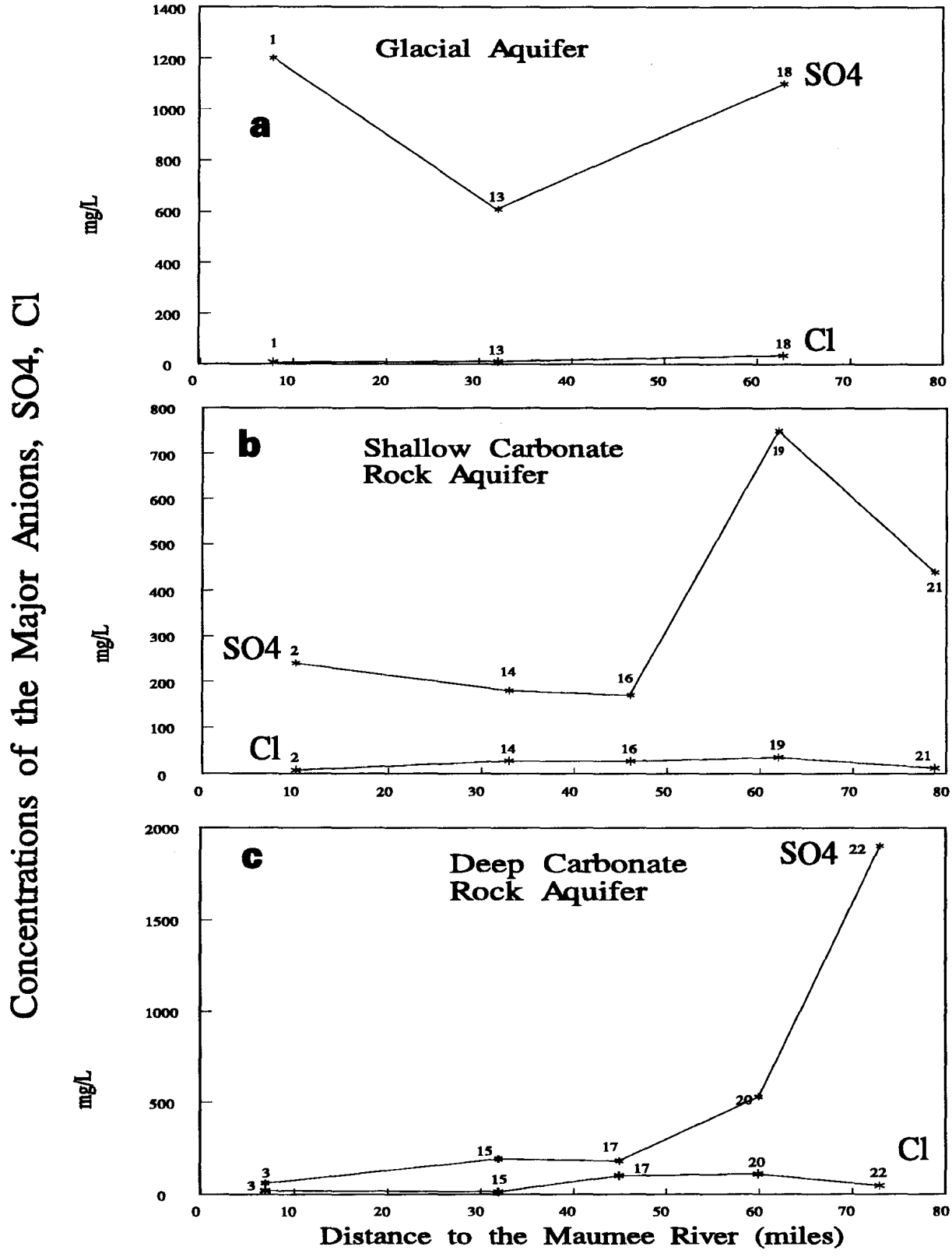

Figure 7. Variation of the concentration of major anions versus distance along the flowpath, a: Glacial Aquifer b: Shallow Carbonate-rock Aquifer c: Deep Carbonate-rock Aquifer.

composed of clean sand and gravel, contains significant amounts of small, soluble rock particles picked up by the Laurentide ice sheet as it several times moved over this section of North America. When the glacier retreated, the scoured material was left as basal till and end moraines and is not of uniform thickness along the flowpath. The low ion concentrations in Well 13 may be due to reduced thickness of glacial sediment and recharge of freshwater into this well.

The variations of the concentrations of anions and cations along the flow path seem to indicate that the deep carbonate aquifer is gaining in concentration between Site I and Site V, the shallow carbonate-bedrock aquifer appears to be fairly homogeneous through out the length of the flowpath, and the concentrations in the glacial aquifer appear to be related to glacial thickness. The cation concentrations of the shallow carbonate aquifer in wells 1, 2, and 3 at Site I, have values between the low concentrations of the deep carbonate-aquifer and the elevated concentrations of the glacial aquifer. Therefore, it appears that the water in the shallow carbonate aquifer at Site I is a mixture of water from the other two aquifers.

The base map used in Figure 2 to identify sample sites and well locations is the subsurface fault map of Ohio delineating the top surface of Middle Ordovician Trenton limestone (Baranoski and Wickstrom, 1991). As noted previously, the BGFZ, with the Maumee fault, the Tiffin fault, and probably many unmapped smaller faults and fault zones are prevalent in northwest Ohio. Injection wells for the disposal of liquid industrial wastes are numerous in northwest Ohio at depths of 2900 feet and greater. The assumption is that once material is injected that deep into basement rock, it will not escape upward into overlying strata and cause contamination of groundwater. If the increased values of sulfate, calcium and magnesium seen at Sites IV and V are caused by

upward leakage of deep brines through the BGFZ, liquid industrial waste could also migrate into these water bearing zones, and do so much more rapidly than may have been anticipated. Therefore, contamination of groundwater could become a potentially serious problem if a large pumping stress is put on the deep-carbonate aquifer by the demands of increased population pressures, agricultural irrigation, industrial uses, or any combination of these. Increased pumping of the deep-carbonate aquifer could actually enhance upward leakage of the industrial waste into the base of the deep-carbonate aquifer.

Summary and Suggested Future Work

The analysis performed in this study has indicated that ground water mixing is occurring at Site I. The same analysis at Sites II and IV will help to determine whether either of them is a recharge zone or a discharge zone. A cross-section drawn along the flowpath reveals that the deep-carbonate aquifer may have been contaminated by brines originating from the Bowling Green Fault.

Strontium concentrations for these samples range from 4,700 μg/L to 27,000 μg/L and are anomalously high considering that average strontium concentrations are usually 20 μg/L to 200 μg/L. The possible medical effects of such high strontium concentrations in drinking water warrant further investigation. The surficial sediment at Sites IV and V is composed of lacustrine deposits of ancestral Lake Erie. Possible ion exchange reactions may be occurring and may be altering the chemical composition of water in the glacial aquifer.

The calcium and sulfate concentrations of water in the deep carbonate aquifer collected along a second line from Bellefontaine to Sandusky Bay and Kelly's Island

should be examined to see whether the extreme elevation of sulfate and calcium concentrations occur in the northwest flowpath examined in this study also occur at Sandusky Bay.

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